A Cost-Effective Approach to Selective IP Paging Scheme Using Explicit Multicast [1]

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Abstract

In this paper, we propose a cost effective IP paging protocol, which can be used for terminal paging in next-generation wireless IP networks. In the existing IP paging protocols, a paging request packet is delivered to access routers belonging to a paging area by unicast or multicast. However, unicast and multicast result in higher cost, so that we present a selective paging algorithm utilizing explicit multicast (xcast). Xcast is a new kind of multicast scheme for small sized groups which uses unicast with low maintenance overhead. In terms of the paging algorithm, we use a selective paging algorithm to minimize the paging cost, by dividing a paging area into several sub-paging areas, while meeting the paging delay bound. In addition, we propose flexible grouping algorithms. For the performance analysis, we develop analytical paging cost and delay models based on the random walk model. Using the models, we compare the selective IP paging scheme using xcast with the existing paging schemes that use unicast or multicast. The results indicate that the proposed scheme significantly reduces the paging cost compared with traditional schemes, especially when the transmission cost is relatively less than the processing cost and the delivery path is not long. In addition, our flexible grouping algorithms, which are adaptive to the session-to-mobility ratio, provide less paging cost and guarantee equal to or less paging delay compared with the existing schemes.

Key words: IP paging, Explicit multicast, Selective paging, Paging cost, Paging delay, Performance analysis.

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1 Introduction

In wireless/mobile networks, since mobile hosts (MHs) are free to move within the coverage area, the network can only keep track of the approximate location of each MH. When a request is made to establish a session with a particular MH, the network needs to determine the MH's exact location within the cell granularity. The operation of the MH informing the network about its current location is known as *location update*, and the operation of the network determining the exact location of the MH is called *terminal paging*. In existing cellular networks, such as the GSM and IS-95 systems, many efficient location update and paging schemes have been proposed in [1–3].

In terms of network architecture for next-generation wireless/mobile networks, IP-based integrated network architecture is widely accepted in the literature [4]. In IP-based wireless/mobile networks, mobility management for Internet services is supported by IP-layer protocols. [2] Consequently, IP-based location management has become the focus of research in this area. In terms of location update, the Mobile IP working groups [8,9] in Internet Engineering Task Force (IETF) proposed various protocols based on Mobile IP. On the other hand, in terms of terminal paging, several protocols were proposed in [10–12]. Unlike the paging protocols in cellular networks, these protocols are based on IP-layer messages so that they are called *IP paging protocols*. With time-constraint multimedia applications (e.g., VoIP and instant message applications) gaining the popularity, IP paging is being considered as one of the essential functions in the future wireless IP networks. In addition, IP paging can reduce the power consumption of MHs [10,15]. However, the previous IP paging protocols did not focus so much on the issue of cost optimization schemes, which provide system scalability, but only on the basic paging architecture, paging procedure, paging area design, and so on [18].

In this paper, we propose an efficient and cost-effective IP paging scheme. Among the various cost optimization factors, which might be considered, we focus on rendering the delivery mechanism of paging request messages more efficient. Since terminal paging in cellular networks is dependent on the specific link technologies, seeking a more efficient mechanism is somewhat redundant. However, a number of different delivery mechanisms (e.g., unicast, multicast, and so on) are available in IP networks. Therefore, it is necessary to determine which mechanism is the best to deliver the paging related messages. In previous works, both unicast ([10]) and multicast ([11] and [12]) were used. Unicast is easy to implement, but it is not an efficient method of paging for multiple

[2] Of course, mobility within an IP subnet will be handled by link-layer mobility protocols [5–7]. However, the focus of this work is the mobility support between IP subnets.

access routers (AR) simultaneously. On the other hand, multicast is an efficient way to page a paging area (PA) consisting of a large number of ARs, however it requires a certain amount of overhead for multicast group management. Therefore, we utilized explicit multicast (xcast) [19] as delivery mechanism for the paging request messages. Xcast is a variant of multicast, which is designed for small sized groups. Unlike multicast, xcast does not require group maintenance, and can therefore support simultaneous paging to multiple ARs with minimal overhead. In other words, xcast is a more cost-effective solution than other delivery schemes. Besides, xcast is an appropriate choice for the selective paging scheme [21–23], as it dynamically adjusts the size of the PA and thus can minimize the paging cost while meeting the paging delay bound. [3]

The rest of this paper is organized as follows. Section II describes related works. In Section III, we provide a comparison study of unicast, multicast, and xcast-based schemes. Section IV proposes a selective IP paging scheme utilizing xcast. In Section V, we develop an analytic model to evaluate the proposed scheme. Section VI shows the numerical results and Section VII concludes this paper.

2 Related Works

2.1 IP Paging Protocol

As mentioned above, several IP paging protocols were proposed in [10–12]. They use different delivery mechanisms to support IP paging.

Zhang et al. proposed a new IP mobility protocol called P-MIP [10]. P-MIP is presented in the form of a paging extension to Mobile IP, which reduces the registration frequency when the MH is in idle state. In this protocol, unicast is used to deliver a paging request message. Although IP multicast would provide better performance than simple unicast distribution, IP multicast is rather complex to implement and manage in wireless access networks. The authors mentioned that it is necessary to consider more efficient support being provided for the delivery of paging request messages in the PA, through the implementation of a lightweight multicast service tailored for such a task.

Ramjee et al. described various architectures, protocols, and algorithms for IP paging service [11]. They discussed three types of paging architectures: home agent paging, foreign agent paging, and domain paging. They used the paging

[3] In this paper, the paging delay is defined as the number of paging operations until the called MH is found

latency and location update rate as the performance metrics to evaluate the performance of different protocols and algorithms under different paging loads and PA sizes. As a result, they showed that the domain paging architecture can support a fairly large load. In contrast to [10], this work used multicast to distribute the paging request messages to the ARs in a PA. In the testbed that they implemented, they used the DVMRP multicast routing protocol in order to reduce the complexity of network management.

Castellluccia et al. proposed an extension to Mobile IP with an adaptive individual paging algorithm [12]. In this scheme, a MH computes dynamically its optimal location area size according to its traffic and mobility patterns. In this work, they assumed that a paging request message is sent to each AR in a PA via some broadcasting mechanism, without giving deep consideration to the implementation issues. However, they mentioned that the use of IP multicast might be a possible solution, but more works are required, especially for dynamic paging areas or selective paging schemes. In [13], they mentioned the use of small group multicast (SGM), which is similar to xcast. However, in this work, since a PA is dynamically constructed by the determination of MH, it results in high computation overhead and energy consumption of the MH. Also, the effect of SGM was not investigated in [13].

In [16], Kempf et al. have performed a comparative study between IP paging protocol and Mobile IP, focusing on the impact of the number of layer 2 (L2) cells per subnet. The simulation results indicate that IP paging achieves a sufficient performance gain only when the number of cells per subnet is sufficiently small. If the number of cells per subnet is larger, Mobile IP provides a comparable performance to IP paging protocol. At the same time, [16] argued that IP paging may be unnecessary if a sufficient L2 paging protocol is available. Unlike the assumptions of [16], we assume that the subnet coverage is sufficiently small in this work. In other words, our scheme is particularly suitable to the case where little or no L2 location management scheme is available, and therefore a subnet covers a small geographical area. Even though there exist only a few radio technologies meeting these characteristics, we expect that the IP radio access network (RAN) technology enables these all IP networks in future [17].

2.2 Explicit Multicast (xcast)

Explicit multicast (xcast) was proposed by the Reliable Multicast Transport (RMT) working group in IETF. IP multicast can be used to minimize bandwidth consumption for audio or video conferencing. On the other hand, xcast can be used to minimize bandwidth consumption for small sized multicast groups. Xcast has many advantages for small multicast groups in comparison with traditional IP multicast schemes designed for very large sized multicast groups. These advantages are listed in [19] and we list here just a few of them.

- The routers do not need to have any maintenance state per session.
- No multicast address allocation is required.
- There are no needs for multicast routing protocols neither intra-domain nor inter-domain.
- No core node, so no single point of failure.
- Xcast can be supported by minimal changes to traditional unicast routes.

However, xcast has several disadvantages. The main disadvantage is the overhead associated with header processing. Each packet contains all of the destination addresses and each destination address has to be processed using a routing table lookup procedure. In other words, an xcast packet with N destinations requires the same number of routing table lookups as N unicast packets. However, since xcast was designed for small sized multicast groups, the packet processing overhead can be reduced by restricting the number of destinations. In the case of the selective paging scheme, the group size of a PA is bounded to a small value. Hence, the processing cost is not a significant problem. In short, xcast is more effective for small sized multicast groups than the traditional IP multicast scheme.

The basic operation of xcast is as follows. First, the source node encodes the list of destination nodes in the xcast header, and then it sends the encoded packet by the simple unicast. Each intermediate router examines the destination list in the IP header and partitions the destinations based on each destination's next hop, and forwards the packet after making an appropriate xcast header. Fig. 1 shows an example of xcast operation. In this example, S refers to a source node and A-D represent destination nodes. When there is only one destination left (at $R5$ in Fig. 1), the xcast packet can be converted into a normal unicast packet. On the other hand, $R4$ generates two xcast packets: one is for destination B and the other is for destinations C and D.

3 Comparative Cost Study: Unicast, Multicast, and Xcast

In this section, we present several requirements of delivery scheme for cost effective IP paging and describe how xcast can meet these requirements. In addition, we develop an analytic model for the cost comparison of unicast, multicast, and xcast, in order to show that xcast is more appropriate than any other delivery mechanisms in terms of paging cost.

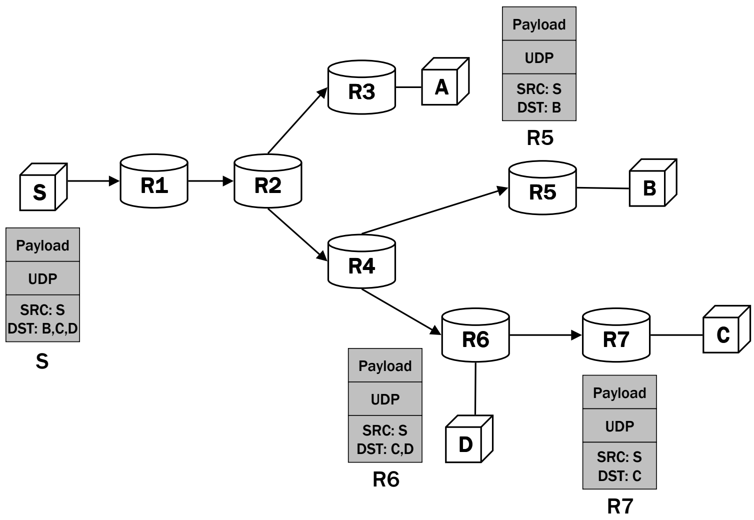


Fig. 1. The operation of explicit multicast

3.1 Requirements

An efficient delivery scheme for paging request messages should meet the following requirements.

- *Low overhead*: As mentioned above, P-MIP [10] uses simple unicast instead of IP multicast. This is because IP multicast entails large overhead such as group management and address allocation. Since terminal paging is performed whenever a new session is initiated, it is essential to minimize overhead as much as possible.
- *Reliability*: If a network entity taking charge of paging in a wireless access network breaks down, the requested session will be blocked and this may have an affect on the perceived QoS of MHs involved. In the case of multicast, group management information is stored in a specific node (e.g., core node). Thus, system reliability may be drastically decreased when this node fails.
- *Scalability*: In terms of protocol overhead, simple unicast may be the best choice. In this work, we assume that a location area consists of about 50 subnets [10] [4] . In this environment, unicast is not appropriate as a delivery scheme due to its non-scalability. Although the number of subnets in a location area is bound to a specific value, efficient delivery scheme should be scalable, so as to adapt itself to the size of the location area.
- *Adaptability*: Selective paging schemes were proposed in order to reduce the paging cost [21–23]. Since selective paging schemes adjust the PA size dy-

[4] In existing cellular networks, a location area consists of around 50 cells, so that we expect that a location area in all IP networks also covers a tens of subnets to support energy-efficient paging functions.

namically according to the MHs' mobility patterns, they are more effective at reducing the paging cost. Therefore, an efficient delivery scheme should be able to support selective paging schemes. However, traditional multicast-based IP paging protocols cannot provide adaptability due to their high maintenance costs.

3.2 Analytical Cost Model

In this section, analytical cost functions are developed to compare the costs of unicast, multicast, and xcast. The costs of these delivery schemes can be divided into three types: link transmission cost (C_L), node processing cost (C_N), and group management cost (C_M). Then, the total cost (C_T) can be expressed as Eq. (1).

$$C_T = C_L + C_N + C_M \tag{1}$$

3.2.1 Link Transmission Cost

Link transmission cost refers to the cost when a paging request packet is delivered to the ARs belonging to a PA. Let L_u and L_m be the average length of a unicast routing path and the total length of a multicast distribution tree, respectively. In addition, let S_u and S_m be the relative paging request packet sizes to the size of a unicast packet when unicast and multicast are used, respectively. Since the multicast packet size is the same as that of the unicast packet, S_u and S_m are both 1. Then, the link transmission costs of unicast (C_L^u) and multicast (C_L^m) are as follows:

$$C_L^u = N \cdot L_u \cdot S_u \cdot \alpha \tag{2}$$

$$C_L^m = L_m \cdot S_m \cdot \alpha \tag{3}$$

where α is the unit transmission cost incurred when a unicast packet is transmitted over a wired link and N is the number of ARs paged by a paging procedure.

Using the same method, the link transmission cost (C_L^x) of xcast can be expressed as Eq. (4).

$$C_L^x = L_x \cdot S_x \cdot \alpha \tag{4}$$

where L_x and S_x are the total length of the xcast distribution tree (Note that there is no explicit distribution tree. However, in this paper, we consider a logical distribution tree for the delivery of xcast packets) and the relative packet size when xcast is utilized. Since an xcast packet contains multiple (N) destination addresses, S_x can be calculated as follows:

$$S_x = 1 + \frac{16 \;\; bytes \times N}{1280 \;\; bytes}$$

where 16 bytes is the length of an IPv6 address and 1280 bytes is the length of a basic IPv6 packet.

According to [20], there exists a relationship between L_u and L_m.

$$L_m = N^{\kappa} \cdot L_u$$

Based on the measurement results, it was proved that κ is about 0.8 [20]. For the simplicity of analysis, it is assumed that the length of the xcast distribution tree is the same as that of multicast (i.e., $L_x = L_m$).

3.2.2 Node Processing Cost

When a paging request packet is delivered to an AR, the packet transverses several intermediate nodes (i.e., routers) and is processed at each node. The main reason for the node processing cost is the routing lookup procedure. To determine the node processing cost, the total number of nodes in the delivery path needs to be calculated. Since the path lengths of unicast and multicast are L_u and L_m, respectively, the number of nodes is $L_u + 1$ for unicast and $L_m + 1$ for multicast. Therefore, the node processing costs of unicast and multicast are given by Eqs. (5) and (6), respectively.

$$C_N^u = N \cdot (L_u + 1) \cdot \beta \tag{5}$$

$$C_N^m = (L_m + 1) \cdot \beta \tag{6}$$

where β is the unit processing cost incurred when a packet containing only one destination address is handled at an intermediate node.

Unlike unicast or multicast, an xcast packet contains multiple destination addresses, so that it requires a number of routing lookup procedures. Specifically, in the case of xcast, all nodes at the leaf level process only one destination address. On the other hand, other nodes, which are not located at the leaf level, handle a number of destination addresses. Therefore, the node processing cost of xcast is as follows:

$$C_N^x = N \times \beta + \sum_{\text{all} \;\; \text{non-leaf} \;\; \text{node} \;\; \text{i}} G(i) \times \beta \tag{7}$$

where N is the number of nodes at the leaf level (i.e., the number of destination ARs) and $G(i)$ is the number of destination addresses contained in the packet when the packet is processed at an intermediate node i.

3.2.3 Group Management Cost

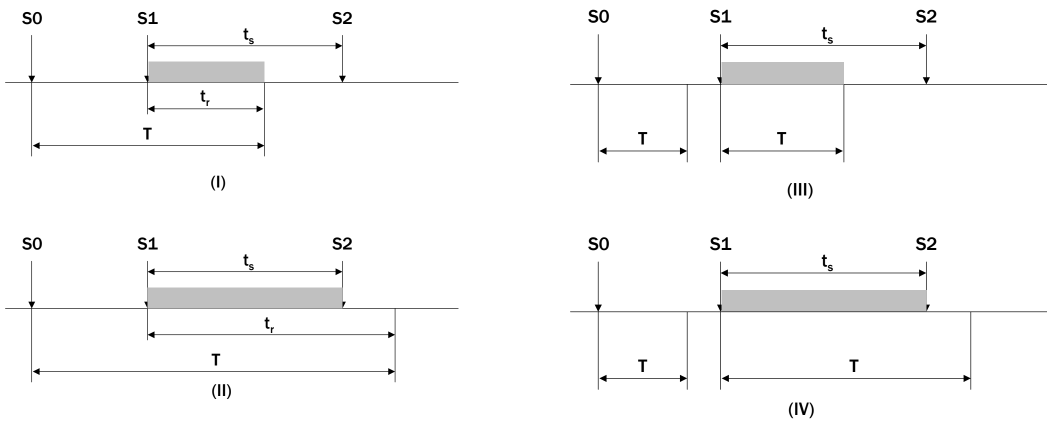
The group management cost is required to construct and maintain a distribution tree. Because there are no explicit distribution trees in unicast and xcast, the group management cost is 0. However, in multicast, the cost of group management is quite high and can be divided into two types: *the tree construction cost* and *the tree maintenance cost*. When multicast is used as the delivery scheme for paging request packets, it is wasteful to construct a distribution tree whenever a new session is initiated. Therefore, we assume that a distribution tree is alive for time period of T after the construction of a multicast tree. If a paging request packet arrives before the timer expires, there is no need to construct a new distribution tree. Let P_V be the probability that a valid distribution tree exists when a paging request packet arrives. If it is assumed that the inter-arrival process for the paging request packet follows a Poisson process with rate of λ_s, P_V can be calculated as follows:

$$P_V = \Pr\{t_S < T\} = \int_0^T \lambda_s e^{-\lambda_s t} dt$$

When a valid distribution tree already exists (i.e., $S1$ in Fig. 2(a)), only the tree maintenance cost during the inter-session time (t_s) or the remaining tree lifetime (t_r) is incurred. On the other hand, if there is no valid distribution tree (i.e., $S1$ in Fig. 2(b)), a new distribution tree has to be constructed and it should be maintained during the the inter-session time (t_s) or the tree lifetime (T). Let r_m be the message delivery rate required to maintain the group membership. The parameter r_m is dependent on the type of IP multicast protocol used. Thus, the group management cost of multicast is as follows:

$$C_M^m = P_V \cdot (r_m \cdot \alpha \cdot \min(E(t_r), E(t_s))) + (1 - P_V) \cdot (\theta_{Tree} + r_m \cdot \alpha \cdot \min(T, E(t_s))) \quad (8)$$

where θ_{Tree} is the tree construction cost.



(a) The multicast tree is valid when $S1$ is arrived.

(b) The multicast tree is not valid when $S1$ is arrived.

Fig. 2. Timing diagram for multicast group maintenance

4 Selective IP Paging Scheme using Explicit Multicast

4.1 Protocol overview

In this section, we present an overview of the selective IP paging scheme utilizing explicit multicast as the delivery method. We assume a functional paging architecture defined in RFC 3154 [18]. The functional architecture consists of the paging agent, tracking agent, and dormant monitoring agent. Although xcast can be used in any types of topologies (e.g., tree, bus, etc), our work assumes a wireless access network with a tree topology as shown in Figure 1. If the wireless access network is assumed to be a bus topology, the gain of xcast-based scheme will be reduced. However, many research works on all IP networks assume the tree topology [11,14], so that we also assume the tree topology.

Our scheme can be integrated with any other paging architectures such as P-MIP [10] and domain paging [11]. When a paging request packet is destined to a MH, a paging agent receives the packet and sends the paging request packet to the ARs in order to find the destination MH. In the selective paging scheme, the number of paging steps to be performed needs to be determined first, before sending a paging request packet to the ARs, depending on the paging delay bound. Let M be the number of paging steps. When determining the value of M, we should consider the paging delay bound and N^*, the feasible xcast group size, which is the number of group members that will enable xcast to perform better than typical multicast in terms of the paging cost.

Once the paging step has been determined, the PA is divided into M sub-PAs and the paging agent sends the first paging request packet to the sub-group denoted by A_0. If the called MH is in A_0, the paging procedure is terminated. Otherwise, a second paging procedure should be performed for the second sub-PA, denoted by A_1. These procedures are repeated until the called MH is found out.

Fig. 3 provides an illustrated example of the selective paging scheme in a PA consisting of 19 ARs. It is assumed that the number of paging steps (M) is 4. In the selective paging scheme, the PA is divided into sub-PAs based on the location where the MH most recently registered. In Fig. 3, first three sub-PAs (A_0, A_1, and A_2) consists of 5 ARs whereas the last sub-PA (A_3) consists of 4 ARs. Namely, each sub-PA is structured as follows. The detailed method to determine the size of the sub-PAs and the members of these sub-PAs will be elaborated in the next subsection.

$$A_0 = \{AR_0, AR_1, AR_2, AR_3, AR_4\}$$
$$A_1 = \{AR_5, AR_6, AR_7, AR_8, AR_9\}$$
$$A_2 = \{AR_{10}, AR_{11}, AR_{12}, AR_{13}, AR_{14}\}$$
$$A_3 = \{AR_{15}, AR_{16}, AR_{17}, AR_{18}\}$$

Let's assume that a correspondent host (CH) would like to initiate a session with a MH, which was last registered at AR_0 but has since moved to AR_{11} without any location registrations because the MH remained in idle state. First of all, the paging agent receiving the paging request message forwards the request to all of the ARs in the first sub-PA (A_0) using xcast. If there is no response from the called MH, the paging agent performs the second paging procedure to the second sub-PA (A_1). Since the MH is currently located in AR_{11}, the MH responds to the third paging request message sent to the third sub-PA (A_2), and at this point the paging procedure is finished.

4.2 Determination of Paging Group Size and Paging Step

Before partitioning a PA into multiple sub-PAs for the selective paging scheme, we have to determine the value of M, the number of paging steps. To determine the value of M, the paging delay bound and the maximum feasible xcast group size (N^*) need to be taken into consideration. As mentioned above, xcast is a more light-weight delivery scheme than multicast, because there is no management cost involved. However, if the group size exceeds a certain value, the packet size becomes too large and this affects the packet processing cost and traffic load in wireless access networks. Therefore, the maximum

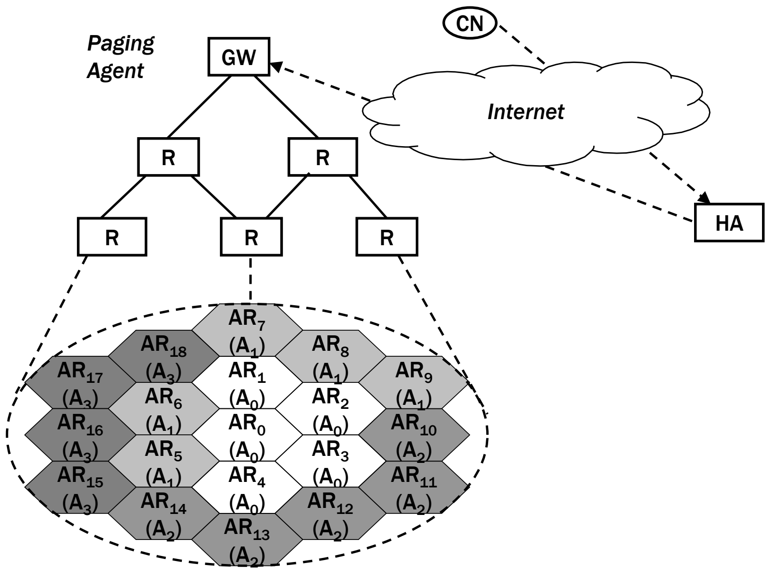


Fig. 3. Protocol overview: Selective IP paging scheme using xcast

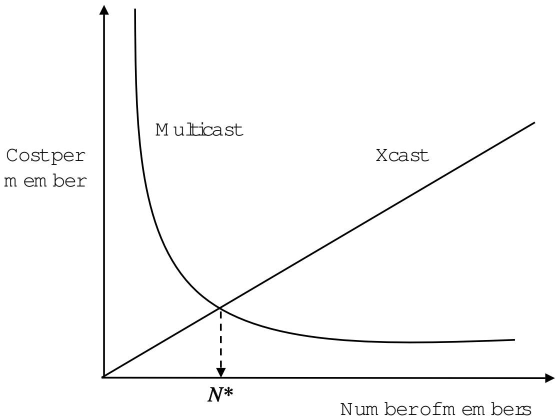


Fig. 4. Cost diagram of multicast and xcast

feasible group size of xcast should be set to a reasonable value by the network administrator. Fig. 4 shows the cost variation as the number of group members is changed. If the number of group members is less than N^*, xcast is a better solution for the paging request message delivery. Otherwise, xcast is likely to induce as much processing overhead as the multicast group maintenance overhead.

Once N^* has been determined, we can decide the value of M based on the following relationship.

$$N_{AR}/N^* \leq M \leq D$$

where D is the paging delay bound and M is an integer value. M has to be larger than the quotient obtained when the total number of ARs (N_{AR}) in a PA is divided by N^*. In addition, M has to be smaller than the paging delay bound (D), in order to satisfy the delay constraints. For example, if there are 61 ARs in a PA, N^* is 20 and paging delay bound is 5, then M can be either 4 or 5. If the paging delay is more sensitive factor, we choose the value of 4 for M. On the other hand, if the paging cost is more important factor, M is set to 5. Namely, there are two types of grouping algorithms when the value of M is determined. One ($G1$) is an algorithm in which the group size is set to $\lfloor N_{AR}/M \rfloor$ and the other ($G2$) is an algorithm in which the group size is set to N^*. For example, if M is 4, 61 ARs in the PA are divided into sub-PAs consisting of 15 ARs, 15 ARs, 15 ARs, and 16 ARs in the case where $G1$ used. In contrast, in the case of $G2$, the 61 ARs are divided into sub-PAs consisting of 20 ARs, 20 ARs, 20 ARs, and 1 AR. $G1$ is more beneficial if the goal is to reduce the paging cost, whereas $G2$ is more advantageous if the objective is to reduce the paging delay. Therefore, in this paper, we utilized both $G1$ and $G2$ as grouping algorithms and compared their performance. Algorithm 1 shows how to determine the xcast paging group size in the case where $G1$ and $G2$ algorithms are employed. $n(A_j)$ represents the number of ARs belonging to the jth sub-PA group.

Algorithm 1 Determination of Paging Group Size

initiate N^*, M, N_{AR};
$i \leftarrow 0$;
if G1 is used **then**
    $divisor \leftarrow \lfloor N_{AR}/M \rfloor$;
else if G2 is used **then**
    $divisor \leftarrow N^*$;
end if
while $i < M - 1$ **do**
    $n(A_i) \leftarrow divisor$;
    $N_{AR} = N_{AR} - divisor$;
    if $N_{AR} \leq 0$ **then**
        can't make group;
        break;
    end if
    $i++$;
end while
if $N_{AR} > N^*$ **then**
    can't make group;
    break;
else
    $n(A_i) \leftarrow N_{AR}$;
end if

4.3 Sub-PA Construction Algorithm

In the previous section, we discussed how to decide the size of the sub-PA group when xcast is used. Once this has been done, we need to construct the sub-PA groups based on the calculated group sizes. In this section, we propose a detailed PA partitioning algorithm, which allows the division of a PA into multiple sub-PAs, which are numbered from A_0 to A_{M-1}.

In the existing selective paging scheme, a PA is divided into sub-PA groups based on the geographical topology [3]. In this paper, a cellular configuration is assumed as shown in Fig. 3. The innermost subnet is labeled "0". Subnets labeled "1" form the first ring around subnet "0" and subnets labeled "2" form the second ring around subnet "0", and so forth. Each ring is labeled according to its distance from the subnet labeled "0", such that ring r_2 refers to the subnets in the second ring away from subnet "0". In general, r_k $(k > 0)$ refers to the kth ring away from the subnet "0". Let $n(r_i)$ be the total number of subnets from ring r_0 to ring r_i.

In [3], the shortest-distance-first (SDF) scheme was introduced for selective paging in dynamic location management. In the SDF scheme, since there is no such concept as the feasible group size, sub-PAs are divided into based on the number of rings. In contrast, in the selective paging scheme using xcast, the sub-PAs are constructed by considering the maximum feasible number of sub-PA group members, which is calculated by means of Algorithm 1.

Algorithm 2 shows how to partition a PA into M sub-PAs. When $n(A_0)$ is greater than $n(r_0)$, all of subnets in r_0 and several of the subnets in r_1 become the members of A_0. In such a case, various criteria can be used to select the subnets in r_1, which become members of A_0. For example, one of the choices might be to select those ARs with smaller paging load. In this paper, the ARs are selected in a random manner for simplicity of analysis. This grouping procedure is repeated until all of sub-PAs have been constructed.

4.4 Paging operation

The last step is to perform terminal paging to the sub-PAs constructed using Algorithm 2. In order to find a MH in idle state, the paging agent sends a paging request message to the ARs of each sub-PA. The paging agent keeps on sending paging request messages until it receives the paging response message from the MH being sought as shown in Algorithm 3. When a MH receives a paging request from the paging agent, the MH checks whether or not it is still located in the same AR in which it was last registered. If the MH is still located in the same AR, the MH sends a paging response back to the paging

Algorithm 2 Paging Group Construction

$i \leftarrow 0$;
$j \leftarrow 0$;
initiate $n(A_j)$;
while $j < M$ **do**
  if $n(r_i) \geq n(A_j)$ **then**
    select $n(A_j)$ subnets in r_i and construct A_j with them;
    $j++$;
    $n(r_i) = n(r_i) - n(A_j)$;
  else
    select all subnets in r_i and construct A_j with them;
    $i++$;
    $n(A_j) = n(A_j) - n(r_i)$;
  end if
end while

agent without any registration. Also, the MH sets its state to active state and restarts its active timer. Otherwise, the MH starts the registration procedure. Following registration, the MH responds to the paging request by sending a paging response.

Algorithm 3 Paging Operation

$i \leftarrow 0$;
while $i < M$ **do**
  Paging agent sends requests to all ARs in A_i;
  if Paging agent receives a response from a MH **then**
    break;
  end if
  $i++$;
end while

5 Performance Evaluation

To evaluate the performance of the selective IP paging scheme using xcast, we developed an analytic model. In terms of the user mobility model, we used the random walk mobility model on the mesh subnet configuration [24] and hexagonal subnet configuration [25]. The term $\alpha((x,y),(x',y'))$ denotes the probability that a MH moves from a subnet (x,y) to a subnet (x',y'). Let $p^K_{(x,y),(x'y')}$ be the transition probability that a MH in subnet (x,y) moves to subnet (x',y') after K movements. Then, $\alpha((x,y),(x',y'))$ can be calculated as the following equation.

i) $(x,y) \neq (x',y')$

$$\alpha((x,y),(x',y')) = \sum_{K>0} p^K_{(x,y),(x'y')} \cdot \theta(K), \tag{9}$$

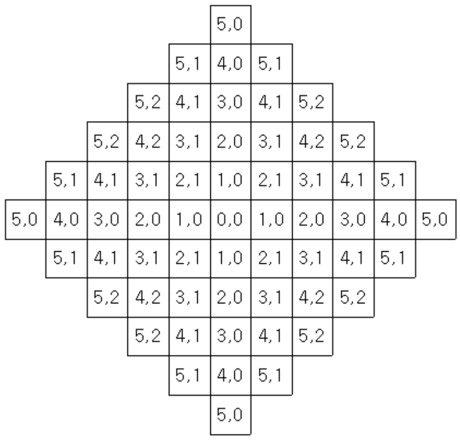


Fig. 5. 6-area mesh subnet configuration

ii) $(x, y) = (x', y')$

$$\alpha((x,y),(x',y')) = \theta(0) + \sum_{K>0} p^{K}_{(x,y),(x'y')} \cdot \theta(K) \tag{10}$$

where $\theta(K)$ is the probability that a MH performs K movements between two consecutive sessions. $\theta(K)$ is given by Eq. (11) [3].

$$\theta(K) = \begin{cases} 1 - \frac{1}{\rho}\left[1 - f^*_m(\lambda_s)\right] & K = 0 \\ \frac{1}{\rho}\left[1 - f^*_m(\lambda_s)\right]^2 \left[f^*_m(\lambda_s)\right]^{K-1} & K > 0 \end{cases} \tag{11}$$

where ρ is the session-to-mobility ratio (SMR) and λ_s is the session arrival rate. The SMR, which is analogous to the call-to-mobility ratio (CMR) in cellular networks, is defined as λ_s/λ_m. $f^*_m(s)$ is a Laplace transform function of subnet residence time with mean of $1/\lambda_m$.

5.1 Mesh Subnet Configuration

In the first analytic model, we consider the random walk model in the mesh subnet configuration shown in Fig. 5. The routing probability for each direction in the mesh subnet configuration is 1/4. In terms of mesh configuration, we use a subnet classification scheme proposed in [24]. The corresponding state diagram is shown in Fig. 6. Since the number of subnets in a location area in the existing cellular network is about 50, we assume a 6-area mesh subnet

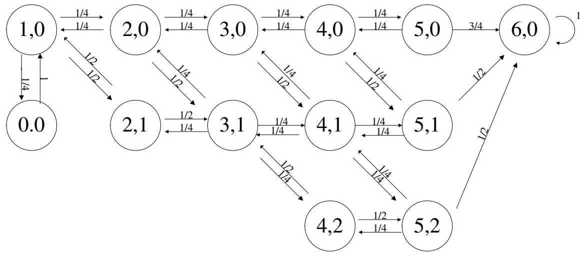


Fig. 6. State diagram in 6-area mesh subnet configuration

configuration, because the total number of subnets in the 6-area mesh subnet configuration is 61. Fig. 6 shows a state diagram in the 6-area mesh subnet configuration. The total number of states is 13.

Let $\mathbf{P}_{mesh}$ be the state transition probability matrix in the 6-area mesh configuration. $\mathbf{P}_{mesh}$ is obtained from the state diagram presented in Fig. 6. Then, it is possible to obtain $p^{K}_{(x,y),(x'y')}$ by calculating $\mathbf{P}^{(k)}_{mesh}$ using Eq. (12).

$$\mathbf{P}^{(k)}_{mesh} = \begin{cases} \mathbf{P}_{mesh} & k = 1 \\ \mathbf{P}_{mesh} \times \mathbf{P}^{(k-1)}_{mesh} & k > 1 \end{cases} \tag{12}$$

5.2 Hexagonal Subnet Configuration

Figs. 7 and 8 show the hexagonal subnet configuration and the state diagram corresponding to this configuration, respectively. In terms of the hexagonal configuration, we use a subnet classification scheme proposed in [25]. The number of total states in the state diagram shown in Fig. 8 is 13.

$p^{K}_{(x,y),(x'y')}$ in the hexagonal configuration can be obtained from Eq. (12) by replacing $\mathbf{P}_{mesh}$ with $\mathbf{P}_{hexa}$, which denotes the state transition probability matrix in the 6-area hexagonal configuration. $\mathbf{P}_{hexa}$ is also obtained from the state diagram presented in Fig. 8.

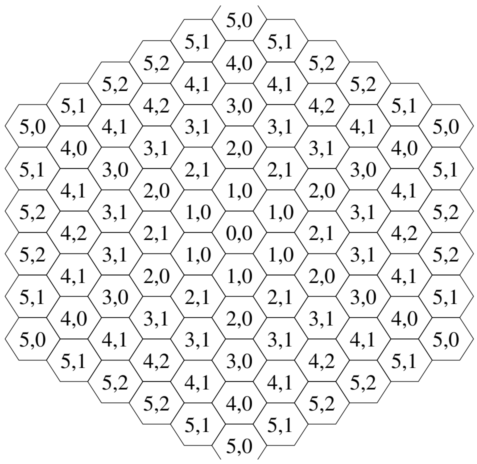


Fig. 7. 6-area hexagonal subnet configuration

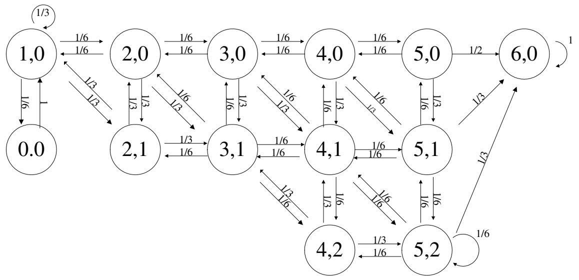


Fig. 8. State diagram in 6-area hexagonal configuration

Table 1
System parameter values

α	β	L_u	r_m	κ	λ_s	T	$S_u(S_m)$
5	1	5	0.1	0.8	0.01	120	1.0

5.3 Unit Paging Cost Function

To determine the different paging costs when the various delivery schemes are utilized, the unit paging cost for each scheme should be determined in advance. To do this, we formulate the unit paging cost function ($C_T(N)$) when the paging group size is N, using the comparative results listed in Section 3. Table 1 shows an example of parameter sets to calculate the unit paging cost function.

Since the transmission cost is generally much larger than the processing cost [20], α and β are set to 5 and 1, respectively. L_m and L_x can be calculated from the relationship of $L_m = N^{\kappa} \cdot L_u$. The message delivery rate for group management (r_m) is dependent on the type of multicast protocol used. We assumed that IP multicast protocol with low message delivery rate (e.g., PIM-SM) is used, so that r_m is set to 0.1. θ_{Tree} can be approximated to $N \cdot L_m$ because all of the ARs belonging to the paging group send a join message to the paging agent, which serves as a core node in the multicast tree. In addition, λ_s and T are set to 0.01 and 120 in this subsection, respectively.

Eqs. (13) and (14) show the unit paging costs as a function of N in the case of unicast and multicast, respectively. $E(t_s)$ is equal to $1/\lambda_s$ and $E(t_r)$ is $T/2$ by the random observer property [29].

$$C_T^u(N) = 25 \cdot N + 6 \cdot N = 31 \cdot N \tag{13}$$

$$C_T^m(N) = 25 \cdot N^{0.8} + (N^{0.8} + 1) + P_V \cdot 30 + (1 - P_V) \cdot (50 + N^{0.8} \cdot N) \tag{14}$$

where P_V is 0.699 when λ_s and T are 0.01 and 120, respectively.

In terms of xcast, the number of processings at non-leaf nodes needs to be calculated. For simplicity of analysis, we assumed that all of the nodes in the wireless access network are organized as a form of balanced binary tree. Then, the number of processings at the non-leaf nodes is equal to $N \cdot \lfloor \log_2 N \rfloor$. Therefore, the unit paging cost function of xcast is as follows:

$$C_T^x(N) = 25 \cdot N^{0.8} \cdot (1 + 0.0125N) + N + N \cdot \lfloor \log_2 N \rfloor \tag{15}$$

5.4 Paging Cost and Delay

The goal of this paper is to design an efficient delivery scheme to reduce the paging cost. Therefore, we do not consider the location update cost and we assume that this cost is identical to three different delivery schemes (i.e., unicast, multicast, and xcast). In other words, the location update cost is assumed to be a constant value.

$$C_L = L$$

where L is the location update cost.

On the contrary, the paging cost is proportional to the unit paging cost and the number of ARs to be paged. As shown in the previous section, the unit paging cost in each delivery scheme is a function of the number of ARs to be paged.

Let $C_P((x,y))$ be the paging cost when the AR where the MH most recently updated is (x,y). The paging cost for the first sub-PA (A_0), is as follows:

$$C_T(n(A_0)) \cdot \sum_{(x',y') \in A_0} \alpha((x,y),(x',y'))$$

On the other hand, the paging cost for the second sub-PA (A_1), is the sum of the paging costs of the first and second sub-PAs. This is because the second paging step is performed only after the first paging step is finished and when the called MH was not found in the first paging step. Based on this relationship, the total average paging cost ($C_P(x,y)$) when the last registered AR is (x,y) can be expressed as Eq. (16).

$$C_P((x,y)) = \sum_{i=0}^{M-1} \sum_{j=0}^{i} C_T(n(A_j)) \cdot \sum_{(x',y') \in A_j} \alpha((x,y),(x',y')) \tag{16}$$

where M is the number of paging steps and A_i is the i-th sub-PA. $n(A_i)$ denotes the number of ARs belonging to the i-th sub-PA. $C_T(n(A_i))$ is a unit paging cost function when the group size is $n(A_i)$.

Let's assume that the probability that the last location updated subnet is (x,y) follows a uniform distribution in $[0, N(n)]$. $N(n)$ denotes the total number of ARs within a PA with n rings. For example, $N(6)$ in hexagonal and mesh subnet configurations are 61 and 91, respectively. In addition, let $N(x,y)$ be the number of subnets with type of (x,y). Hence, the mean paging cost can be calculated as Eq. (17).

$$C_P = \sum_{all \quad (x,y)} C_P((x,y)) \cdot \frac{N(x,y)}{N(n)} \tag{17}$$

In terms of paging delay, the delay is associated with the number of paging steps performed before the MH being sought is found. Let $D_P((x,y))$ be the paging delay when the most recently location updated subnet is (x,y). Then, $D_P((x,y))$ can be obtained from the sum of all of the products of the number of paging steps and the location probability.

$$D_P((x,y)) = \sum_{i=0}^{M-1} (i+1) \cdot U_D \cdot \sum_{(x',y') \in A_i} \alpha((x,y),(x',y')) \tag{18}$$

where U_D is an unit paging delay occurred when a paging procedure is performed. The unit paging delay is dependent on the number of MHs in a subnet and incoming session rate. However, in our work, we assumed an *ideally and* *independently distributed (i.i.d) subnet environment.* Therefore, the unit paging delay for each subnet can be represented by a constant value (U_D). At last, the mean paging delay is given by Eq. (19).

$$D_P = \sum_{all \quad (x,y)} D_P((x,y)) \cdot \frac{N(x,y)}{N(n)} \tag{19}$$

6 Numerical Result

We assume that the subnet residence time follows a Gamma distribution with mean of $1/\lambda_m$ [27,28]. Eq. (20) shows a probability density function (PDF) and its Laplace transform function of the Gamma distribution with shape parameter k and scale parameter b.

$$f_m(t) = \frac{b^k t^{k-1}}{\Gamma(k)} e^{-bt}, \qquad f_m^*(s) = \left(\frac{b}{s+b}\right)^k \tag{20}$$

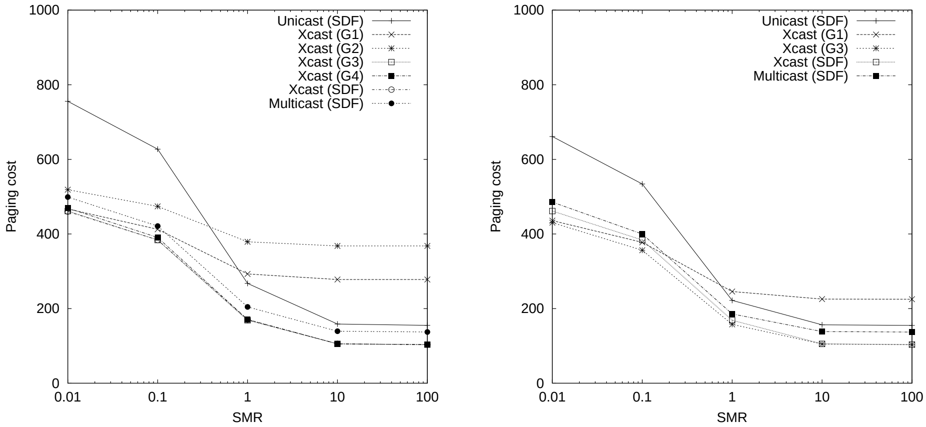
where b is equal to $k\lambda_m$ and $\Gamma(k)$ is the Gamma function, which is defined as $\int_0^\infty t^{k-1} \mathrm{e}^{-\mathrm{t}} dt$. The mean and variance of the Gamma distribution are $1/\lambda_m$ and $1/k\lambda_m^2$, respectively. In the numerical result, b and k are set to 1.0 and 1.0, respectively.

The proposed selective IP paging scheme can be used not only with the static location management scheme but also with the dynamic location management scheme [26]. However, in this analysis, it is assumed that a dynamic location management scheme (e.g., movement-based, distance-based, or timer-based) is used. Therefore, (x, y), which is the last location updated subnet, is simply set to $(0, 0)$. The unit paging delay (U_D) is set to 1.0.

To evaluate the performance of the proposed scheme, we compare the paging costs when xcast, unicast and multicast are used. The paging schemes using unicast and multicast use the SDF scheme for the purpose of paging group construction. In contrast, xcast is incorporated with G1 and G2. As mentioned above, G1 refers to the grouping scenario wherein the total number of ARs is divided by $\lfloor N_{AR}/M \rfloor$. On the other hand, G2 refers to the grouping scenario wherein the total number of ARs is divided by N^*, which is a predefined feasible xcast group size.

For the comparative study, we defined the paging cost gain (G_{pc}) of scheme A as follows:

$$G_{pc} = \frac{Paging \quad cost \quad of \quad multicast}{Paging \quad cost \quad of \quad scheme \quad A}$$



(a) $N^* = 20$ and $M = 4$ (b) $N^* = 20$ and $M = 5$

Fig. 9. Paging cost - Mesh configuration and $N^* = 20$

Namely, the paging cost gain represents the relative effectiveness of the unicast- or xcast-based paging schemes to the multicast-based paging scheme. Therefore, the larger the paging cost gain of scheme A is, the higher the performance of scheme A becomes. On the other hand, if the paging cost gain is less than 1.0, it means that the scheme A is inferior to the multicast-based scheme.

6.1 Effect of Session-to-Mobility Ratio

First, we analyze the effect of session-to-mobility ratio (SMR). Fig. 9 shows the paging cost as the SMR is changed under the mesh subnet configuration. λ_s is set to 0.01 whereas λ_m is changed to 1, 0.1, 0.01, 0.001, and 0.0001. As the SMR increases, the paging cost decreases. This is because a large SMR implies that a MH's mobility rate is low whereas the session arrival rate is high (i.e., a static MH). The static MH is likely to be connected to an AR in the vicinity of the one to which it was last registered when a paging procedure is invoked. Consequently, the paging cost decreases as SMR increases.

As shown in Fig. 9, the multicast-based scheme shows small paging cost because a multicast protocol with low group maintenance overhead is assumed (i.e., r_m is just 0.1). Therefore, the paging cost gains of G1-, G2-, and unicast-based schemes are less than 1.0 for most SMR values.

Specifically, the cost gains of G1- and G2-based schemes are 1.07 and 0.96, respectively, when the SMR is 0.01. However, the cost gains decrease to 0.49 and 0.37 when the SMR is 100. On the other hand, the paging cost gains of unicast-based scheme are 0.66 and 0.89 when the SMR is 0.01 and 100, respectively. In other words, the paging cost gain of unicast-based scheme can be larger than those of G1- and G2-based schemes when the SMR is high.

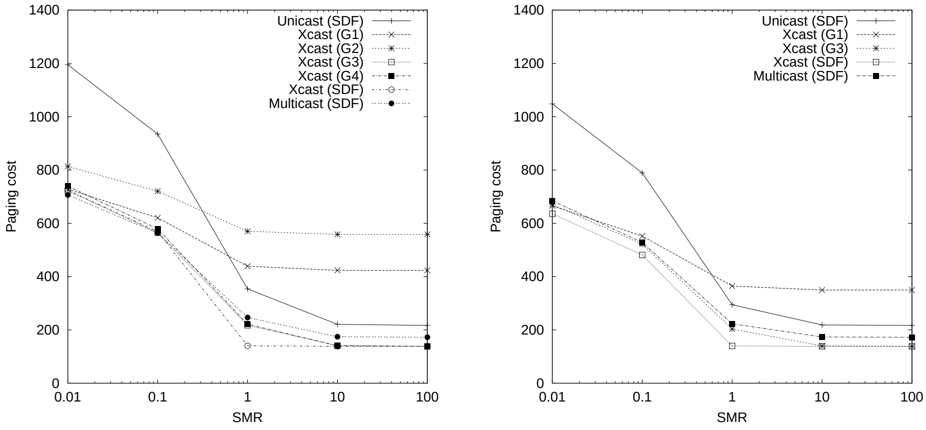
This is because xcast using G1 and G2 creates a sub PA with a fixed size of N^* or $\lfloor N_{AR}/M \rfloor$. However, SDF makes a sub-PA based on the ring area. For example, the number of ARs from ring 0 to ring 1 is 5 (mesh configuration) or 7 (hexagonal configuration). These values are much smaller than N^* or $\lfloor N_{AR}/M \rfloor$, which are typically set to a value between 10 and 30. As mentioned above, the probability that a MH remains connected to an AR in near to the most recently registered AR, increases as the SMR increases. Hence, it is wasteful to make a sub-PA with a larger fixed group size in G1- and G2-based schemes, if the SMR is high. As a result, the paging costs of G1- and G2-based schemes can be higher than that of unicast-based scheme. To overcome these drawbacks, we propose two enhanced grouping algorithms called G3 and G4. Unlike G1 and G2, the first sub-PAs in G3 and G4 consist of ARs located only in ring 0 and 1. However, subsequent sub-PAs are constructed using the same grouping algorithms as G1 and G2.

As illustrated in Fig. 9, the paging cost gains of G3- and G4-based schemes are 1.08 and 1.06, respectively, when the SMR is 0.01. Besides, the paging cost gain is 1.33 for both G3- and G4-based schemes when SMR is 100. Namely, the performance gain of xcast using G3 and G4 is higher than those of unicast and multicast using SDF.

The cost variations in other cases (e.g., $N^* = 20$ and $M = 5$) are almost the same as the result of the case where $N^* = 20$ and $M = 4$. In the case of where $N^* = 20$ and $M = 5$, there are no sub-PAs satisfying the grouping algorithm, G2. Therefore, only G1 and its enhancement, G3, are evaluated.

In addition, we investigate the effect of the proposed group algorithms. To accomplish this, we calculate the paging cost when xcast is incorporated with SDF (refer as *xcast-SDF*). As shown in Fig. 9, Xcast-SDF shows a slightly higher paging cost gain than xcast-G4, while it shows a similar paging cost to G3. However, the difference among xcast-G3, xcast-G4, and xcast-SDF is not notable. This result indicates that xcast is a more dominant factor than grouping algorithm in reducing the paging cost. However, as described in the next section, G1 and G2 has a shorter paging delay than SDF. In short, the proposed grouping algorithms (G1, G2, G3, and G4) provide more flexible solutions. Namely, it is possible to select a more suitable grouping algorithm among G1, G2, G3, and G4 depending on the goal of the paging protocol (i.e., paging cost or paging delay).

In terms of the hexagonal subnet configuration, N^* is set to 30 because a 6-area PA is composed of 91 subnets. In the case of $N^* = 30$ and $M = 4$, the unicast-based scheme exhibits the largest paging cost among various schemes when the SMR is low, whereas G1- and G2-based schemes show larger paging cost than other schemes when the SMR is higher than 1.0. Unlike to Fig. 9, the multicast-based scheme shows the smallest paging cost when the SMR is



(a) $N^* = 30$ and $M = 4$ (b) $N^* = 30$ and $M = 5$

Fig. 10. Paging cost - Hexagonal configuration and $N^* = 30$

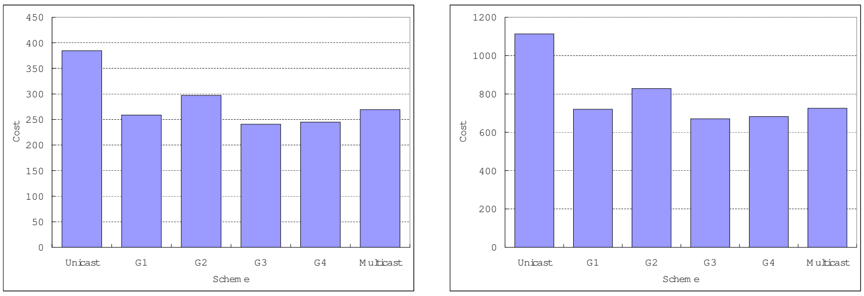
lower than 0.1 while G3- and G4- based schemes exhibit the smallest cost when the SMR is higher than 1.0. In the case of hexagonal configuration, the total number of ARs is larger than that of mesh subnet configuration. Therefore, an additional processing cost of a longer packet may occur when the xcast-based scheme is used. Due to this reason, the multicast-based scheme shows a less paging cost than xcast-based scheme for low SMR values.

The effect of grouping algorithm can be also observed in Fig. 10. Overall trend is the same as that of Fig. 9. When we compare the G1-based scheme (or G3-) with the G2-based scheme (or G4-), the G1-based scheme (or G3-) exhibits less paging cost than the G2-based scheme (or G4-). Hence, the G1-based scheme (or G3-) is a more suitable choice to minimize the paging cost.

In short, although G1- and G2-based schemes show lower paging cost than unicast-based scheme in the case of a low SMR, it has higher paging cost than multicast-based scheme. Specifically, multicast-based scheme with low group maintenance overhead shows lower paging cost than G1- and G2-based schemes. However, when the enhanced grouping algorithms are used (i.e., G3- and G4-based schemes are used), the xcast-based scheme shows less paging cost than unicast- and multicast- based schemes.

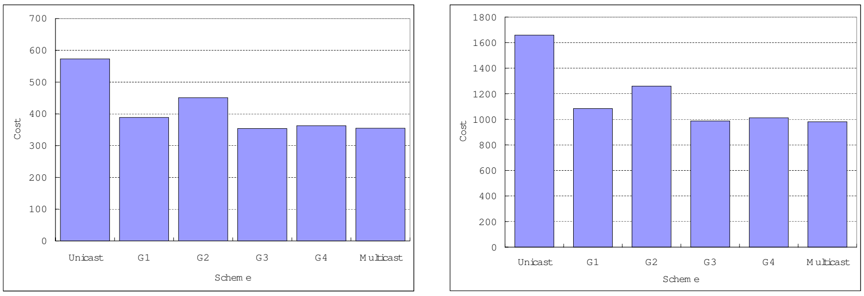
6.2 Effect of The Size of Delivery Path

In this section, we analyzed the effect of the size of delivery path for unicast-, multicast-, and xcast-based schemes. To do this, two different path lengths (e.g., 3 and 9) are evaluated. SMR is set to 0.1 and other parameters are the same as those in Table 1. The delivery path for multicast tree can be calculated using the relation, $L_m = N^{\kappa} \cdot L_u$. As shown in Fig. 11, the paging cost increases



(a) $L_u = 3$ (b) $L_u = 9$

Fig. 11. Effect of different delivery path length (Mesh configuration)



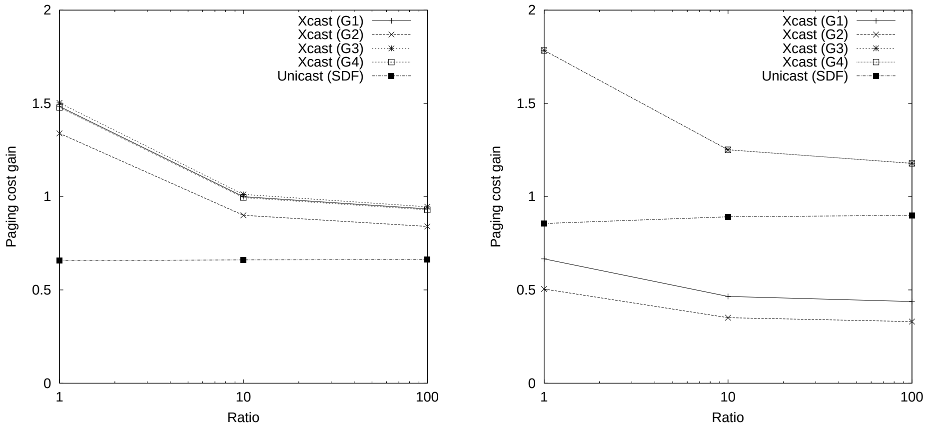
(a) $L_u = 3$ (b) $L_u = 9$

Fig. 12. Effect of different delivery path length (Hexagonal configuration)

as the path length increases. In addition, the cost gains of unicast- and xcast-based schemes decrease as the delivery path length increases. Specifically, the cost gains of unicast-, G1-, G2-, G3-, and G4-based schemes are 0.70, 1.04, 0.91, 1.19, and 1.10, respectively, when L_u is 3. However, when L_u is 9, the cost gains of unicast-, G1-, G2-, G3-, and G4-based schemes become 0.65, 1.00, 0.88, 1.08, and 1.06, respectively. Namely, when the delivery path length is long, it is more efficient to use the multicast-based scheme. This is because using a multicast tree rather than a unicast tree can reduce the packet transmission cost, which is more dominant factor in the case of a long delivery path. This result is more apparent when the hexagonal subnet configuration is used, as depicted in Fig. 12.

6.3 Effect of α/β

As mentioned above, the unit transmission cost is generally much larger than the unit processing cost, so that α and β are set to 5 and 1 in the previous analysis, respectively. In this subsection, we investigate the effect of the variation of the ratio (α/β). Namely, β is fixed to 1 whereas α is changed as 1, 10, and 100.



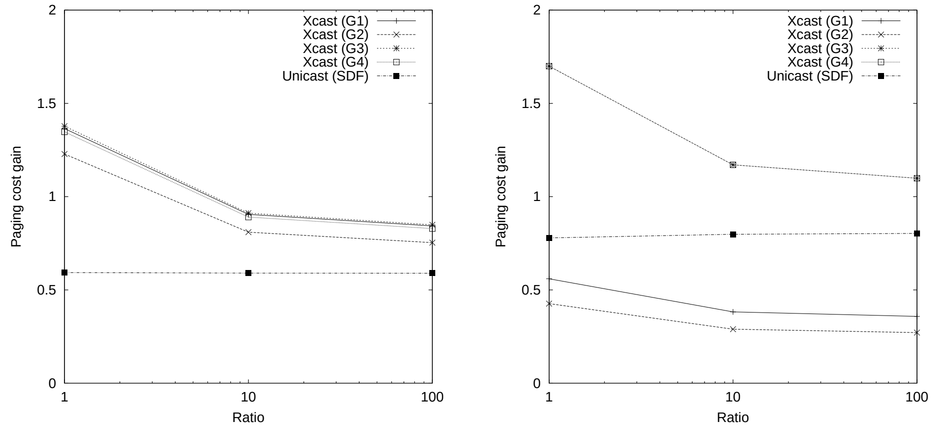
(a) SMR = 0.01 (b) SMR = 100

Fig. 13. Effect of α/β - Mesh configuration ($N^* = 20$ and $M = 4$)

Figs. 13 and 14 show the paging cost gain as a function of α/β. As shown in Figs. 13 and 14, the cost gain slightly decreases as the ratio increases. When the unit transmission cost is relatively higher than the unit processing cost, it is more effective to reduce the transmission cost. In general, multicast delivery is optimal in terms of reducing the transmission cost. Therefore, the paging cost gain to the multicast-based scheme decreases as α/β increases.

In addition, compared Fig. 13(a) with 13(b), the cost gains of G1- and G2-based schemes in the case of a low SMR are higher than those of G1- and G2-based schemes with a high SMR. Namely, since the group management cost in the multicast scheme is reduced due to a higher P_V value when the session arrival rate is high, the cost gain of xcast-based scheme is small when the session arrival rate is high. On the contrary, G3- and G4-based schemes shows higher paging cost gains when the SMR is high. This results reveal that the proposed grouping algorithms can be adaptively used as the SMR is changed to maximize the paging cost gain.

As shown in Fig. 13 and 14, the unicast-based scheme shows the paging cost less than 1.0 for all cases. Especially, in the case of hexagonal configuration, the cost gain of the unicast-based scheme is about 0.59-0.80 while the cost gain in the mesh configuration is about 0.66-0.90. This is because the hexagonal configuration used in this analysis considers more ARs than the mesh configuration. Therefore, when the hexagonal configuration is used, the unicast-based scheme results in higher transmission cost. In other words, it is more efficient to use the multicast scheme when the number of ARs in a PA is large, in order to reduce the transmission cost. In addition, when α/β is high, the paging cost gain of xcast-based scheme decreases. Therefore, muliticast-based scheme is better than the xcast-based scheme in the cases.



(a) SMR = 0.01 (b) SMR = 100

Fig. 14. Effect of α/β - Hexagonal configuration ($N^{*} = 30$ and $M = 4$)

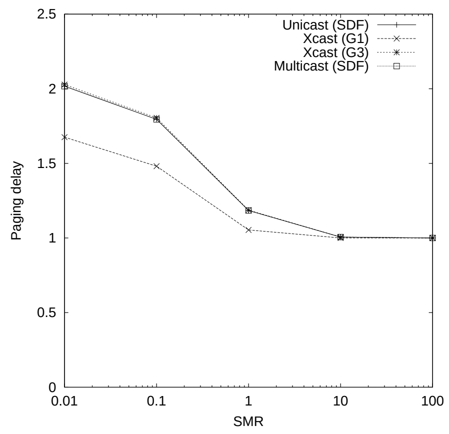
6.4 Paging Delay Analysis

Fig. 15 and 16 show the average paging delay in the mesh and hexagonal subnet configurations, respectively. As shown in these figures, the paging delay decreases as the SMR increases. This is because, as described above, a MH is more likely to remain in an adjacent AR as the SMR increases.

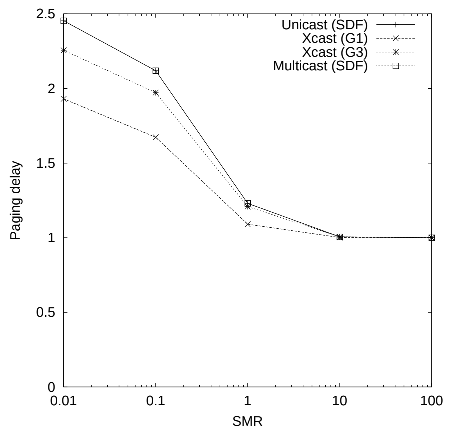
As shown in Fig. 15, G1- and G2-based schemes show the lowest paging delay. The paging delays for the other schemes, except for G1 and G2, are almost the same. In terms of paging delay, how many paging steps are performed is a key factor impacting the average paging delay. When the SMR is small, the paging delay of $M = 4$ is about 80% of the paging delay of $M = 5$. The reason for this reduced paging delay is that the maximum paging step is 4 when M is 4, which is smaller than the value of 5 in the case of $M = 5$.

As mentioned above, G2-based scheme exhibits higher paging cost than G1-based scheme. However, G2-based scheme shows less paging delay than G1-based scheme, as shown in Fig. 15. In addition, the paging delay of both G1- or G2-based schemes is less than that of G3- or G4-based scheme, while G3- and G4-based schemes show less paging cost than G1- and G2-based schemes. Consequently, the results indicate that there is a trade-off relationship between the paging delay and the paging cost. Thus, it is necessary to determine the optimal grouping policy which will minimize the total cost, where the total cost consists of the paging cost and the paging delay cost. However, the difference in the paging delay between G3- and G4-based schemes is not significant.

The paging delay in the hexagonal subnet configuration is presented in Fig. 16. The paging delay of Fig. 16 is slightly less than that of Fig. 15 because N^{*} is 30 not 20. Similarly to the result of Fig. 15, the paging delay of G2-based

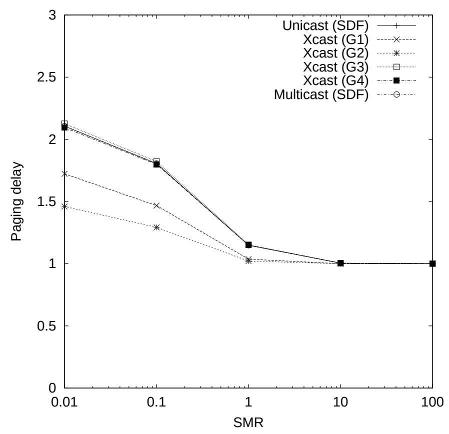


(a) $N^* = 30$ and $M = 4$

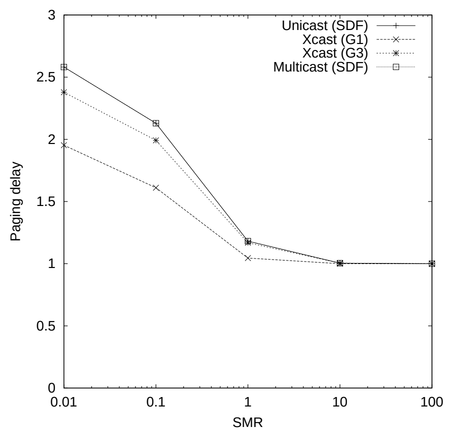


(b) $N^* = 30$ and $M = 5$

Fig. 15. Paging delay - Mesh configuration and $N^* = 30$



(a) $N^* = 30$ and $M = 4$



(b) $N^* = 30$ and $M = 5$

Fig. 16. Paging delay - Hexagonal configuration and $N^* = 30$

scheme is less than that of G1-based scheme. Also, G1- and G2-based schemes show less paging delay than G3- and G4-based schemes. This is because G1- and G2-based schemes create the first sub-PA with a larger group size.

7 Conclusion

In this paper, we presented a selective IP paging scheme utilizing explicit multicast (xcast). The proposed paging scheme is more cost effective than the existing schemes based on unicast and multicast, both in terms of the paging cost and delay. The performance of the xcast-based scheme is highly dependent on the feasible xcast group size and the paging delay requirement. Therefore, for the purpose of flexible xcast-based IP paging, we proposed two types of grouping algorithms (e.g., G1 and G2) and their enhancements (e.g., G3 and G4). For the performance evaluation, we developed the analytic models based on the random walk model under the mesh and hexagonal subnet configurations and calculated the paging cost and paging delay. Using the models, we presented various numerical results, which shows comparison results among the selective IP paging schemes using xcast, unicast, and multicast. The results indicate that the proposed scheme significantly reduces the paging cost compared with traditional schemes, especially when the transmission cost is relatively less than the processing cost and the delivery path is not long. In addition, various grouping algorithms can provide less paging costs by adaptively selecting the grouping algorithm depending on the SMR. In terms of paging delay, the proposed IP paging scheme guaranteed equal or less paging delay compared with the existing schemes.

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